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THE PHYSIOGRAPHY OF MEXICO[1]

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For one who approaches the study of Mexican physiography for the first time, it facilitates matters considerably to acquire in the very beginning a few fundamental concepts, particularly as regards the relations of the provinces of Mexico to those of the United States. We are likely to regard the Mexican provinces as ending abruptly on the north at the International Boundary, and at the south along an irregular political line separating Mexico from Central America. As a matter of fact, the Mexican physiographic provinces extend well into the United States, the natural northern boundary being in a general way the Pecos-Rio Grande, the escarpment of the Colorado Plateau, and the southern terminus of the Sierra Nevada Mountains. As thus bounded, Mexico, from a physiographic viewpoint, includes those provinces hitherto described for the United States under the names of Trans-Pecos Highlands, Arizona Highlands, and Colorado Desert.[2] The natural southern boundary is the isthmus of Tehuantepec. This excludes the states of Tabasco, Campeche, Yucatan, and Chiapas, but physiographically speaking, these political divisions belong to Central America rather than Mexico.[3]

All the topographic features included between these natural boundaries, with the exception of a narrow strip along the Gulf coast, may be traced back to a common feature which came into existence in early Tertiary time, and for which Hill has suggested the name "Cordilleran Peneplain."[4] This peneplain was made on the closely folded Mesozoic sediments. The elevation of the peneplain made the great Mexican Plateau, which in its present condition may be described as a great tilted block, the up-tilted end overlooking the isthmus of Tehuantepec and the down-tilted end lying under the scarp of the Colorado Plateau and along the course of the Rio Grande.

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[1] For complete bibliography see list of references compiled by me and published in *Mining Science*, LXX, Nos. 1745–47.

[2] N. M. Fenneman, "Physiographic Boundaries within the United States," *Ann. Ass. Am. Geog.*, IV, Pl. 1.

[3] E. Bose, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, XXXI, 15–16.

[4] R. T. Hill, "Growth and Decay of the Mexican Plateau," *Eng. and Min. Jour.*, LXXXV, 681–88.

On this plateau erosion and vulcanism have carved and molded a variety of topographic forms. The products of one or both of these factors characterize definite areas, and applying the definition that a physiographic province is an "area which is characterized throughout by similar or closely related surface features, and which is contrasted in these respects with neighboring areas,"[1] we find that the prominent topographic divisions of Mexico become its true physiographic provinces.

These provinces may be gathered for convenience in discussion into two groups: one, the northern, having a general north-south alignment, and the other, the southern, having a general east-west alignment (see accompanying map, Fig. 1). In order from east to west the members of the northern group are the Gulf Coastal Plain, the Anahuac Desert Plateau, the Sierra Madre Occidental, and the Sonoran Desert. Below these, in succession southward, come the Volcanic, the Sierra del Sur, and the Tehuantepecan provinces. Where province names are not self-explanatory, reasons for them will be given in the text to follow. In our discussion of the provinces we will begin with the Sierra Madre Occidental, for the reason that it is the oldest feature of Mexican topography and will aid in orienting us, so to speak, when we come to the discussion of younger features with more complex histories.

THE SIERRA MADRE OCCIDENTAL PROVINCE

Definition and boundaries.—The Sierra Madre has been defined as "a vast area of circumdenudation," "a higher island of summit survival,"[2] "a great plateau, fringed by mountains on the east, trenched by deep canyons in the center, and bordered by a wild and rugged complex of mountains on the west."[3] "It is not to be regarded as a single chain or mountain mass, but rather a group of chains, generally of the same orientation, successively rising, one above the other, from west to east, separated by depressions of various widths and furrowed by streams of more or less importance."[1]

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[1] Fenneman, *op. cit.*, p. 87.

[2] Hill, *Eng. and Min. Jour.*, LXXX, 633.

[3] W. H. Weed, *Trans. A.I.M.E.*, XXXII, 444.

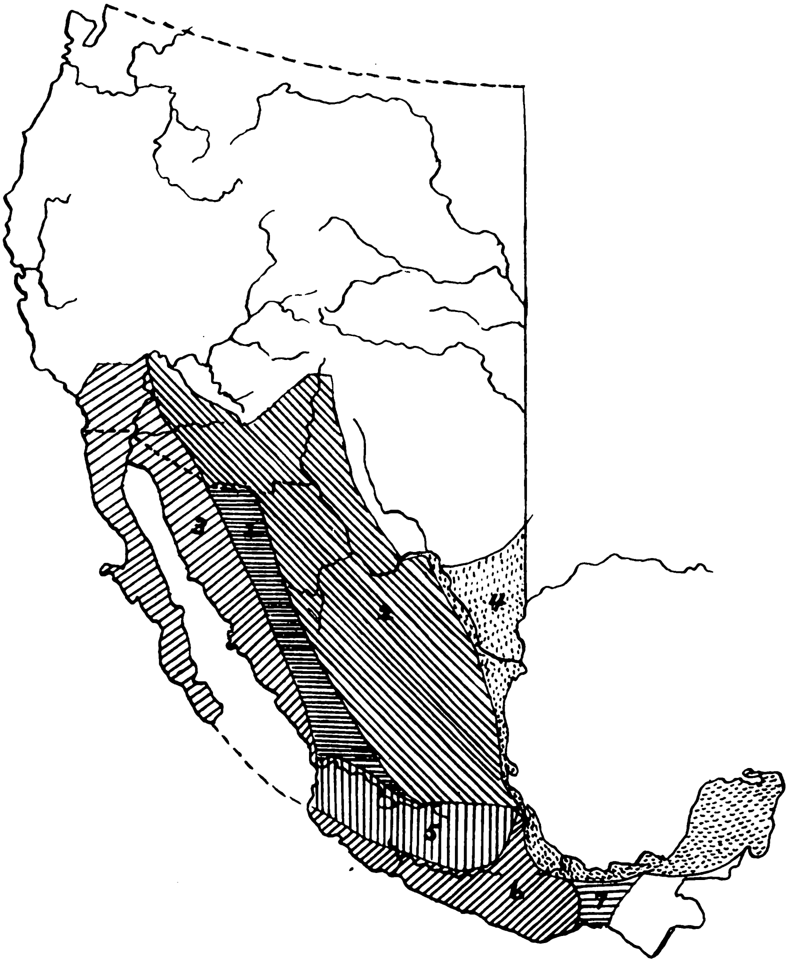

FIG. 1.—Physiographic Provinces of Mexico

1. Sierra Madre Occidental.
2. Anahuac Desert Plateau.
3. Sonoran Desert.
4. Gulf Coastal Plain.
5. Volcanic.
6. Sierra del Sur.
7. Tehuantepecan.

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[1] E. Ordonez, *Inst. Geol., Mex.*, IV.

This province extends from near the International Boundary southward, roughly parallel to the Pacific coast, to the valleys of the Rio Grande de Santiago and the Rio Lerma. It has been suggested that the Chiricahua Range of Arizona may mark its former extent to the northward, and show the transition between it and the closely related province of the Colorado Plateau in the United States.[1] Throughout the greater part of its extent it will average 100 miles in width, but in the south it attains a width of 300 miles or more.

There are many Sierra Madres in Mexico; so many, in fact, as to be confusing to the casual reader of Mexican geography. The Sierra Madre Occidental, however, is the real "mother" Sierra, the progenitor of all the other Sierras in Mexico. If a section be drawn across Mexico from the Atlantic to the Pacific in almost any latitude, it will be found that every feature on the profile of that section, save a narrow strip of coastal plain, is related in some manner to this Sierra (see accompanying profile sketches, Fig. 2).

The northern boundary has been drawn at the International Boundary, where the Sierra Madre Occidental Mountains end rather abruptly and overlook the vast stretches of desert plateau to the northward.

The western boundary, from Naco, Arizona, to the mouth of the Rio Yaqui, follows the Rio Sonora and the Rio Moctezuma, which flow in structural valleys at the foot of the mountain scarp.[2] From Trinidad, Sonora, to the Rio Grande de Santiago, Tepic, this western line marks the highest escarpment overlooking the desert below, and is coincident with the state boundaries separating Chihuahua, Durango, and Zacatecas on the east from Sonora, Sinaloa, and Tepic on the west. There is no doubt that these boundaries between states are the result of natural selection, because the prominent topographic break makes an indisputable parting between political divisions. This line, which marks the present limit of the eastward retreat of the plateau, was determined by one of the prominent N. 45° W. fault lines which cut the plateau.[3]

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[1] Hill, *Eng. and Min. Jour.*, LXXXIV, 631.

[2] See the Bartholomew map of Mexico, published by the National Geographic Society.

[3] J. D. Villarello, *Guides des excursions, 10th Inter. Cong. Geol. Mex., 1906*, No. 18.

The southern boundary of this province has been placed at the canyons of the Rio Grande de Santiago and the Rio Lerma; not arbitrarily, but because at this place there is a sharp change in the strike of the massive folded sediments.[1] North of this line the structural trend is generally northwest–southeast, while south of it the trend is more nearly east-west. South of this line, also, erosional down-cutting in the plateau ceases to be the controlling factor in the making of the topography, and gives way to volcanic piling-up on it.

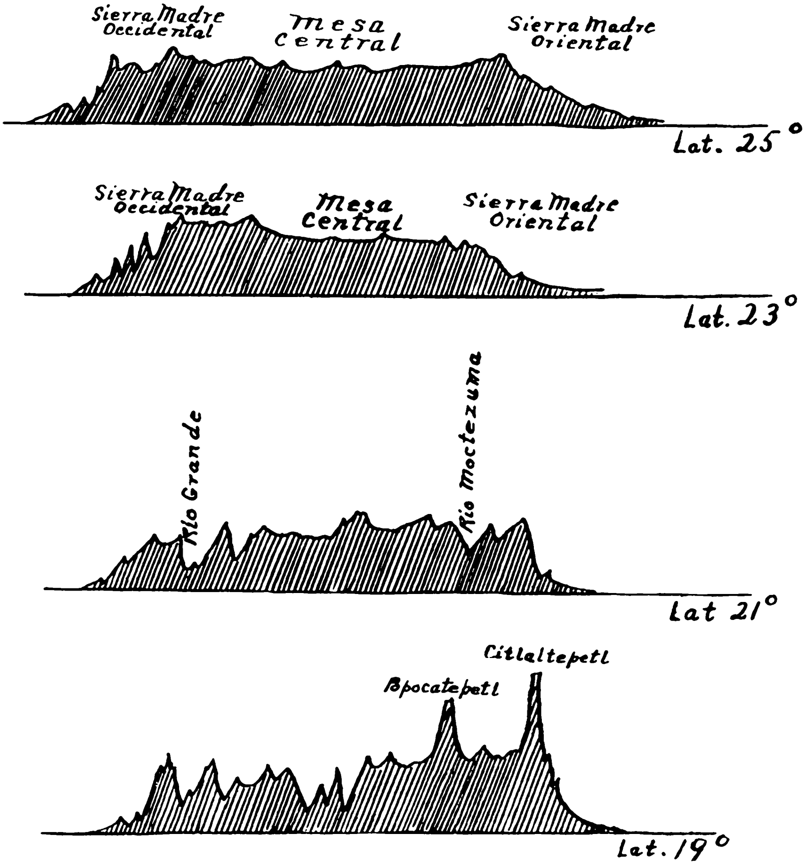

FIG. 2.—Profile of Mexican Plateau. (After J. G. Aguilera.)

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[1] Ordonez, *op. cit.*

The eastern boundary of this province begins at the International Boundary and runs in a general southerly direction through the states Chihuahua, Durango, Zacatecas, San Luis Potosi, and Queretaro to the Valle de Mexico. It is not a sharp line like the other boundaries of the province, but has been rather arbitrarily chosen throughout the greater part of its length, though not without certain criteria. It has been drawn to pass near such cities as La Junta, Parral, San Miguel, and Zacatecas, which are known to be situated at the eastern foot of the mountains. Between these cities the line has been drawn to pass through the points marking the sources of the small "suicidal" streams which rise near the border of the mountains and lose their small quantities of water by evaporation and percolation soon after reaching the desert below. The want of suitable topographic maps covering large areas makes a more accurate drawing of this line impossible. Its location cannot be far from correct, however, for it coincides with the line on the Willis geological map of North America, which separates the mountain country, where the volcanic cap rock is thick, from the desert to the east, where erosion has removed the extrusives and exposed the underlying Cretaceous sediments.

Topography.—In a general way the topography of this province may be described as "a succession of narrow and continuous northwest-southeast ridges, with foothills, separated by broad and continuous longitudinal valleys" which grow wider toward the coast.[1] The even skyline which one might expect to result from the uplift and dissection of a peneplain is not everywhere apparent, because of subsequent volcanic flows of uneven thickness; although viewed over broad areas there is a certain evenness of summits which is apparent in spite of the flows, which were not of the cone-building type, but more like those which resulted in the formation of our Columbia Plateau.

An east-west profile of the Sierra Madre in southern Chihuahua and Sonora shows an average elevation of about 7,000 feet on the east, rising to 10,500 feet at the Continental Divide, and dropping again to about 6,800 feet at the western scarp.[2] The term "Continental Divide" should not be understood too literally, for it is not

[1] J. G. Aguilera, *Inst. Geol. Mex.*, V.

[2] Weed, *op. cit.*

between the Atlantic and Pacific, but between the Pacific and the interior basins of the Anahuac Desert province.[1] There is also a drop in elevation of a few thousand feet from south to north in conformity with the slope of the tilted plateau block which constitutes the Mexican country.

The Sierra Madre Occidental is generally regarded as a mountainous country, and experienced geographers write of its "ridges," but it is important to note that the roughness of its topography is due to down-cutting rather than upheaval or upbuilding; in other words, the slopes of the region are to be regarded as canyon walls rather than mountain flanks.

This province has no important drainage to the east save by the Rio Conchos and the Rio San Juan, both tributary to other streams. All of the other streams which rise in the mountains and flow eastward are of the "suicidal" or "lost"[2] type and disappear soon after reaching the desert below, or flow into undrained lagunas (lakes), where their water is gradually evaporated. The profound work of dissection and denudation which one sees in progress east of the mountains is not due to these streams, but to other processes which will be described later.

On the west, normal processes of erosion are under way, and numerous subsequent streams are working headward and pushing back the western scarp of the plateau at a rapid rate. In many places these have captured the streams occupying the longitudinal structural valleys, the latter entering the former at angles varying from 45° to 90°.[3] Some of these western streams, particularly the Aros, the Fuerte, and the Rio Grande de Santiago, have incised their canyons a mile below the top of the plateau, and emphasize the fact that the rugged character of the country is not due to upward departures from the general level, but to profound down-cutting in the plateau. The greatest depression is in the Grand Canyon of the Bolanos, a tributary of the Santiago. The depth of this canyon is accentuated by the fact that it lies at the foot of the maximum crest of the mountains—the Sierra de la Yesca.[4] Experienced travelers testify that the scenery to be found in these canyons rivals that of our own Grand Canyon, which was produced by the same causes and at the same time.

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[1] E. O. Hovey, *Bull. Phil. Geog. Soc.*, No. 4, p. 247.

[2] Hill, *Eng. and Min. Jour.*, LXXXIV, 633.

[3] Aguilera, *op. cit.*

[4] Ordonez, *op. cit.*

It is along the courses of these westward-flowing streams that the dentate character of the sierras is seen to the best advantage. Their longitudinal tributaries separate chains or mountain masses, the western slopes of which are marked by precipitous fault scarps. The eastern slopes of these masses being more gentle, the profile is clearly imitative of the teeth of a saw.[1]

Many of the longitudinal stream valleys, before being tapped by the westward streams, were intermontane basins. On the sides of these valleys are now to be found undeformed, stratified beds, which were for a long time unaccounted for. They are now regarded as loosely cemented dêbris which had been carried down the slopes and deposited in the basins, which, when filled with water, formed lagunas, and constituted "settling tanks," as Hill has termed them,[2] where the detritus was roughly classified according to size and deposited in layers. They are of course of a past, but quite recent, geologic age.

The general structure of this province may be described as a series of folds, varying from a close, even recumbent, type, to broad swells, passing out northward into monoclines, over the erosion-beveled edges of which are spread flow upon flow of eruptive lavas. Le Conte, twenty years ago,[3] proposed the theory that these Sierras were formed by intense folding movements in Early Tertiary time, followed by profound drops at the sides of faults parallel to the folds; that along these lines of less resistance, successive and prolonged volcanic eruptions took place, and that subsequent active erosion accentuated the escarped form which affects most of the slopes. Later studies pursued by prominent Mexican geologists have confirmed this theory.[4]

In the canyon of the Aros there have been counted as many as nineteen separate lava flows, one above the other, with intervening beds of tuff and local conglomerate derived from the disintegration of the preceding flows. Erosion has affected unequally these tuffs and the harder lavas (rhyolites and dacites), and in consequence there have been produced, on many of the slopes, several terraces or "shoulders."[1]

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[1] Ordonez, *op. cit.*

[2] Hill, *Trans. A.I.M.E.*, XXXII, 163.

[3] Le Conte, "The Origin of Mountain Ranges," *Jour. Geol.*, September-October, 1893.

[4] Ordonez and Aguilera, *Inst. Geol. Mex.*, IV.

Physiographic history.—The history of the present Sierra Madre Occidental begins properly with the uplift which brought the Cretaceous sediments out of the sea. This uplift continued to a considerable altitude and was accompanied by profound deformation, which took the form of close folds and overthrusts passing into faults, the strike of the entire system being approximately north-south. This uplift, which was an event of early Tertiary time, inaugurated the first erosion cycle, which, when completed, had removed some thousands of feet of rock and resulted in the formation of the "Cordilleran Peneplain."[2]

Following this peneplanation, toward the close of the Miocene,[3] another uplift occurred, accompanied by widespread vulcanism. Numerous vents were opened over the province, from which flowed an enormous quantity of slightly viscous lava. Uplift continued; in fact, is still in progress. In the meantime, a second erosion cycle began, during which there has been removed at least two thousand feet of volcanic rock, and which has seen the larger westward-flowing streams incise their canyons a mile below the top of the plateau.[4]

Recent work on the Grand Canyon of the Colorado has indicated a third erosion cycle, intermediate between the two just described.[5] It is impossible to determine from the data at hand whether it included the entire Mexican Plateau. It is certain that in some places the early eruptives (andesites) as well as the intrusives (diorites and granites) were deeply eroded before the later eruptives (rhyolites and dacites) appeared. However, the evidence of this third cycle is obscure, even where displayed to the best advantage, whereas the evidence of the two cycles described above is perfectly clear to experienced physiographers.

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[1] Hovey, *Bull. Am. Geog. Soc.*, XXXVII, 531.

[2] Hill, *Eng. and Min. Jour.*, LXXXV, 681.

[3] Ordonez, *op. cit.*

[4] Hill, *Science*, N.S., XXV, 710.

[5] L. F. Noble, *Am. Jour. Science*, XXIX, 374–80.

At some date subsequent to the completion of the first cycle extensive orogenic movements changed the whole structural trend from north-south to about N. 45° W.[1] The profound faulting which accompanied these movements blocked out the entire country into its present shape, determined most of the prominent structural features, and opened avenues for the intrusion of vast igneous bodies which have been responsible for the primary mineralization of the province.

THE ANAHUAC DESERT PLATEAU

Definition and boundaries.—Many names have been applied to this portion of the old Mexican Plateau, such as the Mesa Central, Chihuahua Desert, and Anahuac Plateau. Hill has suggested the name Anahuac and it will be used in this paper, for it seems eminently appropriate to fasten upon this decayed remnant of a former widespread feature the name of the aboriginal race which inhabited it, and which centuries ago went into decadence along with it. The terms "desert" and "plateau" are included, for they are descriptive of the province. Furthermore, these terms serve to correlate this province with those of the United States which Fenneman has included under the name of desert plateaus.[2]

The Anahuac Desert Plateau is a degraded area of scattered block mountains and intervening "bolson" desert. It extends from the plains of Texas and New Mexico and Arizona on the north,[3] southward through the Mexican states of Chihuahua, Coahuila, Nuevo Leon, Tamaulipas, San Luis Potosi, Queretaro, and Hildalgo to the Valle de Mexico and the base of Xinantecatl (Nevado de Toluca).[4] The portion lying north of the International Boundary is well known under the names of Trans-Pecos Highlands and Arizona Highlands.

The northern boundary line runs eastward from the great bend of the Colorado River, along the edge of the Colorado Plateau, through Silver City, New Mexico, then turns northeastward and passes the southern ends of the San Juan and Sangre de Cristo mountains.

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[1] Hill, *Science*, N.S., XXV, 710.

[2] Fenneman, *op. cit.*

[3] G. B. Richardson, *El Paso Folio*, *U.S. Geol. Survey*.

[4] Ordonez *et al.*, *Trans. A.I.M.E.*, XXXII, 259.

The eastern boundary follows the western slope of the Pecos valley to the southern edge of the Stockton Plateau.[1] Here it turns eastward along the Balcones scarp to the junction of the Pecos and Rio Grande. Here it turns again and continues in a southerly direction almost to Vera Cruz. In this part of its course it has been drawn on the 500-foot contour of the Bartholemew map, which is practically coincident with the western limit of sediments younger than Late Cretaceous as mapped by Willis. In the field, it should coincide with the line separating the undeformed sediments of the Gulf Coastal Plain from the folded rocks of the plateau.

The western boundary runs southward from the great bend of the Colorado River at the foot of the Grand Wash and Cottonwood Cliffs,[2] which represent the eastward-retreating scarp of the old plateau,[3] to the Gila River. From the Gila to Naco, Arizona, it follows the Rio San Pedro to the International Boundary. From this point southward the line has already been described in connection with the Sierra Madre Occidental province.

The southern boundary is drawn close to the edge of the volcanic area from Nevado de Toluca to Jalapa. It separates two easily distinguishable topographic divisions. North of it, denudation dominates the topography; south of it, great volcanic piles raise themselves above the general level. The Mexican National Railroad from Vera Cruz to Mexico City follows the same line for a considerable distance, and it is, I think, a safe assumption that the railroad survey took these topographic features into consideration.

Topography.—It is not possible to give a single descriptive statement of the topography of this province. Broadly speaking, it is a wide expanse of territory in which great islands of isolated mountain blocks rise above a vast sea of desert. This description may be applied with all faithfulness to the province through its entire north-south extent, but an important exception must be made with reference to the eastern and southern borders. In these places it is actually mountainous.

Beginning with the Sierra del Carmen and the Sierra del Burro, inconspicuous ranges of 5,000 feet altitude or less, just across the

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[1] I. Bowman, *Forest Physiography*, Pl. I.

[2] *Ibid.*

[3] Hill, *Eng. and Min. Jour.*, LXXII, 563.

Rio Grande from the Stockton Plateau, a chain rises above the desert level and increases gradually in height southward until it forms the Sierra Madre Oriental. These mountains increase in height southward until they attain truly magnificent proportions, with peaks reaching 10,000 feet or more in Hidalgo and Queretaro, where they meet eastward-extending spurs of the Sierra Madre Occidental and merge with them. The Gulf slope of these mountains is in many places a scarp dividing the plateau from the Gulf Plain. It is probable that this scarp marks the position of a great fault line having at some points a vertical displacement of at least 4,200 feet.[1] These mountains are not a continuous north-south barrier, like the western sierra, and the ramifications of the desert "extend through the passes of the limiting chains in many places and establish easy communication with the coastal lowlands."[2]

Travelers across the Trans-Pecos region of Texas and New Mexico are more or less familiar with the topographic forms which will be described as characteristic of the greater part of this province. Prominent among these are the north-south trending ridges, separated by broad plains—in part constructional and in part plains of degradation—many of the latter being of the basin type called "bolsons," from the Spanish word meaning "purse." A section across the Anahuac Desert Plateau in almost any latitude would show the same topographic features—"numerous isolated mountain ranges with intervening pocket valleys or wide expanse of undulating plain."[3] The general desert level has an altitude of from 2,000 to 4,000 feet, while the mountains generally rise above 5,000 feet, with an occasional peak ascending to 8,000 feet or more.

Other prominent features of the topography are the "lost" mountains, lagunas, medanos, and a peculiar formation known as "La Brisca."

Lost mountains are isolated mountain blocks standing in the desert, and so far removed from the main mass of mountains as to have no apparent connection with them. They are simply outliers (monadnocks) which have resisted denudation more effectively than the surrounding territory.

[1] F. L. Nason, *Econ. Geol.*, IV, 421.

[2] Aguilera, *Inst. Geol. Mex.*, VI.

[3] Hill, *Eng. and Min. Jour.*, LXXXV, 681.

Lagunas are shallow ephemeral lakes, mostly found in the lowest parts of the bolsons, and fed by streams whose sources are in the neighboring mountains and which flow only during time of storm—the "suicidal" streams previously discussed.

Medanos are sand hills or dunes, similar to those of our lake shores or the Great Basin. They consist of finely disintegrated particles, derived from the weathering of the plateau, which are constantly moved about, frequently in a general northeast direction, by the high winds.

In our discussion of the Sierra Madre Occidental province we mentioned a peculiar, stratified deposit of a past but recent geologic age which had been formed in intermontane basins. It must be remembered that the Anahuac Desert Plateau province formerly presented the same topography as is found in the Sierra Madre Occidental province at the present time, the latter by its definition being a survival of former widespread conditions. The dissection and weathering of the type of deposit mentioned results in a characteristic feature known in Mexico as "La Brisca." It is a superficial volcanic agglomerate consisting of rhyolitic tuff carrying subangular fragments of other igneous rocks and which weathers into striking forms due to inequalities of hardness—pinnacled cliffs, domes, pillars, etc.[1]

The Rio Panuco and the Rio Conchos, a tributary of the Rio Grande, drain the greater part of the province, although a considerable area known as the Bolson de Mapimi in Chihuahua and Coahuila is without exterior drainage. This great bolson is not a single basin, for within it are to be found mountains of considerable elevation; but its elevations and depressions are so disposed that none of the water falling in it (which is a negligible quantity) reaches the sea.[2]

The Rio Grande is an interesting river from a physiographic viewpoint. At one time it emptied its waters into a great laguna that lay southwest of the present site of El Paso. It appears then that a headward-working tributary of a stream which probably had the course of the present Pecos-Rio Grande tapped this laguna and diverted its waters to the Gulf of Mexico. But the channel of the stream was far to the south and west of the present course of the Rio Grande, to which it was gradually crowded by encroaching volcanic flows.[1] It has never recovered itself, and in the vicinity of El Paso wanders about with an abandon that perplexes those who are charged with the duty of maintaining a definite line for the International Boundary.[2]

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[1] Hovey, *Bull. Am. Geog. Soc.*, XXXVII, 539.

[2] Bose, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 19.

The desert plains of this province are of two types—degraded and constructional. The former are the result of denudation of greater plateau heights; the latter represent valleys or basins filled by detritus derived from the degradation of neighboring areas.

The mountains show several types of structure, though generally they are tilted fault blocks. Mountains in which an igneous core has been thrust up through the sedimentaries are not uncommon. Many are of the "mesa" type, the volcanic capping protecting the soft limestones beneath from erosion. A typical "lost" mountain is to be found in the Santa Eulalia, situated a few miles southeast of Chihuahua City. It is a mass of folded Comanchean limestone mantled by superficial eruptive material, tuffs, and cinders, and at present rises about 1,500 feet above the desert level. Scattered over the surrounding desert lie piles of débris derived from the denudation of the original mountain, which stood several thousand feet above its present height.

Physiographic history.—The history of this province coincides with that of the Sierra Madre Occidental until the beginning of the second erosion cycle. In brief, its known history begins with the withdrawal of the waters of the Gulf of Mexico and the emergence of the land mass at the end of the Cretaceous period. Then followed deformation along general north-south lines, with accompanying or subsequent elevation to a height sufficient to be susceptible of active erosion. This elevation, which probably occurred during the early Eocene,[3] ushered in the first erosion cycle, which ended with the base-leveling of the country to the condition of the Cordilleran Peneplain.

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[1] Richardson, *El Paso Folio, U.S. Geol. Survey.*

[2] Mrs. A. S. Burleson, *Natl. Geog. Mag.*, XXIV, 381.

[3] Ordonez and Aguilera, *Inst. Geol. Mex.*, IV.

A little speculative interest is attached to the making of this first peneplain. In humid regions the processes of erosion tend ultimately to reduce the land surface to a base-level which is at or near sea-level; but in an arid region of basin-drainage type erosion cuts down hills and aggrades the basins, so that the plane of reference to which both hills and basins will be brought ultimately is not sea-level, but some higher indeterminate level.[1] Now if aridity characterized this early Tertiary base-leveling period in Mexico (a condition of which we are not certain), it is possible that the peneplain resulting from the erosion of the first cycle was not made at sea-level.

Following this peneplanation another uplift took place; in fact, is still in progress. This was accompanied in the beginning, probably Miocene time,[2] by orogenic movements which altered the entire structural trend to a general northwest-southeast direction.[3] There also occurred at this time widespread volcanic activity, both extrusive and intrusive.

In the second erosion cycle inaugurated by this uplift there were probably a number of stages, for there exist in many places old erosion surfaces made on both sedimentaries and volcanics, covered and filled by later volcanic flows. At the end of the volcanic period erosion became the dominant factor in determining the topography, and has remained so until the present time; and it is this epoch in the history of the province that holds the greatest interest from a physiographic viewpoint.

All of the features of the topography of this province which we have previously discussed are due to erosion agencies peculiar to an excessively arid region. In humid climates water in some form is the chief agent of erosion, but in this province nothing is more scarce than water, and the excessive denudation which has taken place must therefore be attributed to other agents. Chief among these is a large diurnal temperature variation. A midday temperature of 130° F. is not uncommon over a large part of the province, and a midnight temperature of 50° F. is usual throughout most of the year in the same places. This gives a maximum daily variation of 80° F., and it is safe to assume that the mean daily variation is not less than 50° F.

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[1] W. M. Davis, *Jour. Geol.*, XIII, 381.

[2] Ordonez, *op. cit.*

[3] Hill, *Science*, N.S., XXV, 710.

These sudden and excessive changes in temperature produce expansion and contraction stresses which even the hardest rocks are unable to withstand, and consequently they crack, splinter, and chip off. Then by gravity these particles are dragged down the slopes, comminuting each other as they go, until when they reach a certain minuteness of size they are seized by the strong, ever-blowing desert wind, which, like a great winnowing machine, fans them away. Much of this rock dust is carried out to sea, some of it perhaps is carried hundreds of miles to the northeast to add to the accumulation of loess on our Great Plains. Sheet floods following storms play an important part in erosion, but they are quite subordinate to the process just described. In the words of Hill, "the Mexican Plateau is being literally blown away."[1]

THE SONORAN DESERT PROVINCE

Definition and boundaries.—This province is the most degraded portion of the old Mexican Plateau. It is 1,700 miles long and lies between the Sierra Madre Occidental on the east and the Pacific Ocean on the west. It includes parts of Nevada, California, and Arizona in the United States, and the Mexican states of Baja California, Sonora, Sinaloa, and Tepic.

The northern boundary line runs from the edge of the Colorado Plateau near the great bend of the Colorado River westward to the southern terminus of the Sierra Nevada Mountains. It has been drawn to agree with the line marking the southern edge of the Great Basin as described by Fenneman[2] and Bowman[3] and requires no further justification.

The western boundary extends southward from the southern terminus of the Sierra Nevadas, between the Tehachapi Mountains of the Coast Ranges and a group of mountains which Ransome has referred to as the Sierra de Los Angeles, and reaches the coast between Los Angeles and San Diego.[4] From this point southward it coincides with the Pacific coast line to Cape San Lucas, and then cuts across the mouth of the Gulf of California to Cape Corrientes, where it closes with the southern boundary.[1]

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[1] Hill, *Science*, N.S., XXV, 710.

[2] *Op. cit.*

[3] *Op. cit.*

[4] J. S. Diller, *Science*, N.S., XLI, 1045.

The eastern boundary has been described in connection with the Sierra Madre Occidental and Anahuac Desert Plateau provinces.

The southern boundary is really a prolongation of the eastern boundary, which makes a turn to the southwest from the valley of the Rio Grande de Santiago to Cape Corrientes.

Topography.—Although there is a certain homogeneity of topography which distinguishes this province from its neighbors, there is, nevertheless, a minor diversity of features within its boundaries. The features which force themselves upon the attention of the student of physiography are as follows: (1) a great structural trough, occupied by the Gulf of California, the Salton Sink, and the Coachilla and Imperial valleys;[2] this trough, if not an actual southern extension of the same, is at least analogous to the great downwarp of the Pacific coast which is occupied in succession northward by the San Joaquin, Sacramento, and Willamette valleys and the Puget Sound basin; (2) a destructional coastal plain of varying width bordering the open ocean and the Gulf of California; (3) a foothill region bordering the western foot of the Sierra Madre Occidental and the Arizona Highlands, of which the mountains of the Peninsula of Lower California are a counterpart.[3]

The bottom of the structural trough is below sea-level from Riverside County, California, to Cape Corrientes, with the exception of the delta of the Colorado River, which lies slightly above sea-level and separates the submerged portion, known as the Gulf of California, from the Salton Sink and the Coachilla and Imperial valleys, which are at present land surfaces, though one point is 275 feet below sea-level.

The coastal plain is very narrow where it borders the open ocean and on the east side of the peninsula. On the mainland it assumes a wedge shape, and varies in width from zero in Tepic to 70 miles in the northern part of the province. It is nearly level, with few elevations above 200 feet, and "plainly the bottom of the Gulf of

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[1] Ordonez and Aguilera, *Inst. Geol. Mex.*, IV and VI.

[2] Bowman, *op. cit.*, p. 235.

[3] C. Botsford, *Eng. and Min. Jour.*, LXXXIX, 223.

California until recently."[1] The fact that it has but recently emerged does not make it a constructional plain, for only a superficial bed of sediments covers the surface, denuded before the last submergence. Northward into Sonora, Arizona, and California this subdivision of the province grades quite imperceptibly into the lowlands of the Colorado Desert, where it loses its featureless coastal plain identity and is characterized by old valley floors with intermittent streams, old valleys filled with alluvium, and isolated mountains half-buried under alluvium, plains eroded by sheet floods descending from adjacent mountains, and true desert areas, of which the Mojave Desert is typical.[2]

The foothill region represents a less advanced stage of erosion of the edge of the old plateau. It is also wedge-shaped, its width varying from 20 miles in the south to 100 miles in the north. Its average altitude is less than 2,000 feet, though here and there peaks rise to 5,000 feet or more.[3] These are outliers, representing the former extent of the plateau, and are genetically analogous to the lost mountains of the Anahuac Desert Plateau province, previously discussed.

Northward these foothills grade into mountains of a somewhat different kind—the Basin Range or fault-block type. They still may be regarded as remnants derived from the old plateau but which have suffered recent faulting, as well as the erosion of two cycles.[4] The mountains of the peninsula are counterparts of the foothills of the mainland. According to Botsford the correlation of the two is perfect, as indicated by the "extent and characteristics of the Miocene rhyolytes and dacites on both sides of the gulf."[5] Northward it is probable that these peninsular mountains grade into the type of which the San Bernardino Mountains are characteristic, and not into the Coast Ranges, as they are generally mapped.[6]

The average altitude of these peninsular mountains is higher than the mainland foothills, on account of less active erosion due to an almost entire absence of rainfall, and in places peaks rise almost to the level of the original peneplained surface of the old plateau; for instance, Santa Catalina 10,135 feet and Mount San Bernardino 10,630 feet.

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[1] C. Botsford, *Eng. and Min. Jour.*, LXXXIX, 223.

[2] Bowman, *loc. cit.*, p. 237.

[3] Botsford, *loc. cit.*

[4] Bowman, *op. cit.*, p. 236.

[5] Botsford, *loc. cit.*

[6] Diller, *loc. cit.*, and Ordonez and Aguilera, *op. cit.*, p. 52.

In the northern part of the province there are numerous features that have many of the earmarks of glaciation—cirques, moraines, kettle holes, etc.[1] In the San Bernardino Mountains there is scarcely any doubt that these features are of glacial origin, the evidence presented by physical characteristics being supported by a boreal flora and fauna in the higher parts of the range; in Arizona and Sonora, however, there is some question concerning their glacial origin, and able geologists have held different opinions on this point. One holds that they are due exclusively to ice action;[2] another attributes them to volcanic brecciation and subsequent sheet flood erosion.[3] Inasmuch as either process would produce subangular fragments of varying size and would transport them to considerable distances from their point of origin, it is difficult to decide which is the more probable theory. Recent field work has not contributed much to the discussion.

The prominent drainage feature of this province is the Rio Colorado. It is of interest to physiographers for several reasons. Although it flows hundreds of miles through an arid country, without tributaries, and loses much of its original volume by evaporation, it delivers at its mouth a great volume of water, particularly from April to June. In this water is a larger average amount of suspended matter per unit volume than in that of any other North American stream, about twenty thousand parts per million, or enough to cover one hundred square miles of territory to a depth of one foot in a year. This accounts for its rapidly growing delta, and the cutting off of the Salton Sink and the Imperial and Coachilla valleys area.[4]

The lower course of this stream was consequent upon the surface of the great downwarp between the peninsula and the mainland.[5] In the bed which it found in this trough the river cut a canyon, the mouth of which was on the coast somewhere between Cape San Lucas and Cape Corrientes.[1] This cutting may have been coincident with the elevation succeeding the downwarping or it may have occurred at some indefinitely later time. It is certain, however, that the depth of the gulf is not due alone to drowning by the sea, but largely to stream-bed corrasion incident to elevation. The maximum corrasion is estimated by Botsford to have been at least 6,000 feet.[2]

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[1] Merrill, *Science*, N.S., XXIV, 117.

[2] *Ibid.*

[3] W J McGee, *Science*, N.S., XXIV, 178.

[4] Bowman, *op. cit.*, pp. 238–40.

[5] Botsford, *loc. cit.*

On the peninsula, but four small streams cut the coast line of more than two thousand miles. This is due to the fact that there is little or no precipitation. There are extensive areas on the peninsula where not a drop of rain has fallen in many years, which are characteristically desert in aspect and condition, even to the extent of supporting a fauna which apparently does not require water. In striking contrast to these conditions is the Sierra Pedro Martir, located in the northern part of the peninsula. This is a high plateau remnant, forested with conifers, and threaded here and there by small watercourses which flow through grassy and even marshy meadows.[3] Here cactus and yucca give way to conifers; and the horned toad and desert fox are replaced by mountain sheep and deer. In short, the region is the habitat of a fauna and flora akin to that found in the western mountains of the United States.

The reason for this change from desert conditions which exist on all sides is to be found in the height of the area, which causes it to receive considerable snowfall from December to April. The water from the melting snow lies close to the surface of the undrained plateau during a large part of the remainder of the year and gradually finds its way to springs scattered at lower altitudes. This condition dies out gradually down the gentle slope to the Pacific but ends abruptly at the scarp overlooking the gulf.

On the mainland, east of the gulf, there are numerous short streams which have their sources high up in the Sierra Madre Occidental, and receive considerable water during the rainy season. Many of these are dry during the greater part of the year, but are, nevertheless, active agents of erosion when carrying the excessive run-off which follows precipitation on the bare desert slopes. The Sonora, Yaqui, Fuerte, and Rio Grande de Santiago rise farther back in the mountains and have a continuous flow. The canyons which these latter streams have cut through the mountains and foothills are of profound depth, and present to the traveler a sublimely rugged scenery, not to be surpassed on the continent.

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[1] Ordonez and Aguilera, *op. cit.*, p. 52.

[2] Botsford, *loc. cit.*

[3] North, *Am. Geog. Soc. Bull.*, XXXIX, 544.

The structure of this province is quite complex on account of the extensive folding, faulting, and vulcanism to which it has been subjected. A cross-section would show folded sedimentaries, upon the beveled edges of which sheets of volcanic material are spread, and into which dikes, plugs, sills, laccoliths, and other igneous bodies have been intruded. The whole mass is broken by numerous faults, chiefly of the N. 45° W. system, though east-west faults are common and occasionally profound, one in the Cananea district having a vertical displacement of at least 1,000 feet.[1] The topographic effect of the predominating N. 45° W. faults is to be seen in the scarps of the western border of the Sierra Madre Occidental and of the eastern border of the peninsular mountains.

Physiographic history.—When this province emerged from the sea after receiving its thick deposit of Mesozoic sediments it was subjected to stresses, which resulted in close folding and in the making of the great synclinal trough previously described. Following this, in early Tertiary time, there came a period of erosion which beveled the edges of the folded strata and resulted in the making of the "Cordilleran Peneplain," previously described.

After the country had been base-leveled, vulcanism began to play an important rôle, and during the Miocene great masses of volcanic material were poured out from numerous vents, completely burying the sedimentaries. Coincident with this a second uplift occurred, giving the streams renewed energy and causing erosion to become the dominant process in the making of the topography. It was during this second uplift, which probably is still in progress, that the Colorado River cut its trench several thousand feet deep through the Pacific trough.[2] The remainder of the province was not seriously affected in the beginning by the erosion of this period,

[1] M. L. Lee, *Econ. Geol.*, VII, 324.

[2] Botsford, *op. cit.*

because of its thick volcanic cap. During the early stages of this second cycle the synclinal trough was depressed, allowing the sea to encroach as far north as the Salton Sink, about 200 miles farther northwest than at present. At that time, "the mouth of the Colorado River was at Yuma, sixty miles from its present location, and was gradually building a delta that extended southwest toward the Cocopa Mountains. Deposition continued until the upbuilding of the delta had completely separated the head from the rest of the gulf, and converted the floor of the former into an inland sea."[1] At numerous times since, the Colorado has alternately emptied into the Gulf and into the lake or inland sea which it created.

The greater part of the degradation of the province has occurred during recent epochs of the period of second uplift. When once the volcanic capping is worn through, the softer sediments beneath erode with remarkable rapidity, and the larger westward-flowing streams have cut canyons of abysmal depths in them, in their short but steep courses to the sea. The smaller intermittent streams working headward into the plateau are attacking the softer rocks wherever exposed, and, with the sheet floods which follow the torrential downpours characteristic of the province, are doing a work the results of which are not so likely to attract attention as canyon-cutting, but which are infinitely more profound in the degradation of the plateau.

THE GULF COASTAL PLAIN PROVINCE

Definition and boundaries.—This province is a plain composed of recent and undeformed marine sediments. Being a southern extension of a similar feature in the United States it has no proper northern boundary, but is continuous through the Gulf states and up the Atlantic as far as Long Island.

Its western boundary has been described in connection with the Anahuac Desert Plateau province.

The eastern boundary, in common with that of the remainder of the coastal plain in the United States, may be taken as the border of the continental shelf, and is, of course, many miles east of the present coast line, which is but an incidental feature.

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[1] Bowman, *op. cit.*, p. 239.

Inasmuch as both eastern and western boundaries of this province might be extended into Central America, it has no southern boundary as far as Mexico is concerned.

It is evident that the coastal plain is divisible into two parts, one submerged and the other a land surface. Of the former there is little to be said, save that its depth below sea-level is in most places very slight; the charts of the United States Coast and Geodetic Survey show but 30 fathoms at a distance of 125 miles out from the mouth of the Rio Grande.

The landward portion has its greatest width along the International Boundary, where it attains a width of about 225 miles. South of Brownsville the province narrows suddenly and continues to grow narrower until at Tampico it has practically no development at all. This condition continues with more or less variation as far as Vera Cruz. South of this point there is a gradual widening which increases with distance until, in the peninsula of Yucatan, the plain has a maximum width of over 300 miles.

Topography.—The most prominent topographic features of this province lie close to the coast line—a multitude of spits, bars, coastal islands, lagoons, and salt marshes. The greater part of the surface above tide is a featureless flat, which terminates rather abruptly at the foothills of the Sierra Madre Oriental. It is not possible to draw a straight line of any considerable length between the coastal-plain type of topography and that of the mountains. Indeed, it is common to find jutting headlands of the Sierras and reduced areas of intrusive rocks almost down to the water's edge,[1] and on the other hand to find recent marine sediments in the coves 40 or 50 miles inland. This condition has already been explained and is mentioned again only to justify the generalization of the boundary line.

No large or important streams cross the province south of the Rio Grande. The paucity of streams and the number of lakes are noteworthy features of the peninsula of Yucatan. This condition is closely related to the lithology of the bedrock. This consists of thick beds of limestone and shale of Cretaceous age. Where the coastal plain is narrow, as in the vicinity of Tampico, these deposits are deeply covered by marine sands supplied by the débris washed down from the eastern edge of the plateau, but on the peninsula, where the plain is very wide and the greater part of it at a considerable distance from the mountains, the limestones are close to the surface. These limestones are of a particularly soluble character, and on account of the low, flat, or undulating surface, the heavy rains of the region soak into the ground and percolate through them, developing great caverns (*cenotes*). Where the cavern roofs have fallen in the natural channels of circulation are stopped, and water fills the depression, forming shallow ponds (*akalches*).[1] In other places the waters continue to circulate downward until they strike a stratum of impervious shale, along which they move in underground channels to the sea, or upon which they form subterranean lakes. These form the only permanent natural sources of water on the peninsula, and as a result they are of considerable economic value.

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[1] V. R. Garfias, *Jour. Geol.*, XX, 666.

Physiographic history.—As in other sections of the Atlantic Coastal Plain, the later history of this province may be summed up as a series of submergences and emergences. At times, perhaps several times, the present land portion has been under water. At other times the present submerged portion has been above the sea, even to the edge of the continental shelf. The tendency at this time is toward a submergence of the present land surface portion.[2]

THE VOLCANIC PROVINCE

Definition and boundaries.—This province embraces a high mountainous strip of country in which the axes of folding are aligned east-west, and in which the departures from the general level are upward instead of downward, as elsewhere over the plateau. The province extends across Mexico in an east-west direction from Cape Corrientes to Jalapa. Early geographers called it the "Cordillera de Anahuac,"[3] but the term has fallen into disuse because it is now recognized that it is as much an integral part of the great Mexican Plateau as the Sierra Madre Occidental.[4]

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[1] Huntington, *Bull. Am. Geog. Soc.*, XLIV, 801; V. R. Garfias, *Inst. Geol. Mex.*, III, 18.

[2] C. Sapper, *Inst. Geol. Mex.*, III.

[3] Virlet de Aoust, *Bull. Soc. Geol. de France*, 2d Ser. XXIII, 14–15, 1866.

[4] Aguilera, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 7, p. 3.

The northern, western, and eastern boundaries have already been described in connection with other provinces. The southern boundary line extends in a general way from Cape Corrientes along the courses of the Rio Armeria, the Rio Tepalcatepec, the Rio Balsas, the Rio Mexicala, and the Rio Atoyac, all of which skirt the southern edge of the recent volcanic flows, to the vicinity of Esperanza, and then around the volcano of Orizaba and the Cofre de Perote to Jalapa. The change in topography when one crosses the boundaries of this province are sharp and definite, and if not always comprehended in a single view, at least become apparent within a few miles.

Topography.—Viewed from any commanding eminence, this province presents a wildly rugged topography—"a variegated sea of rolling, timber-covered, constructional, volcanic hills, mesas, peaks, and monticules, alternating with basin valleys and plains."[1] The great altitude of the major portion of the province (8,000 feet and upward) is not due alone to the higher altitude of the plateau itself, although it is 5,000 feet above El Paso, but to the vast quantities of volcanic material which have been ejected from numerous vents and piled upon it.

This volcanic material consists not only of lava, but also of tuffs and pumice, in some places *in situ* and in others as old lacustrine deposits. The material from which these lacustrine deposits were made was derived by erosion from the surrounding volcanic heights and carried into the lakes, raising their waters until they overflowed into neighboring streams, and finally filling the lakes completely. As many of these Pliocene and Pleistocene lake beds were of considerable areal extent, their deposits have effaced much of the pre-existing volcanic topography.[2]

It is probable that the plain upon which the higher peaks rest was formed simultaneously with them. According to Ordonez the more fluid portions of the magma were ejected from the vents by violent explosions and raised into such prominent andesitic cones as Popocatapetl and Ixtaccihuatl, while the denser basalts flowed from connecting fissures to form the "badland" plains surrounding them.[3]

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[1] Hill, *Eng. and Min. Jour.*, LXXIX, 410.

[2] Ordonez, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 8 and plate.

[3] Ordonez, *ibid.*, No. 1, p. 4.

Figures are totally inadequate to express the amount of this extrusive material. Even using the largest familiar units of volume they would run into orders which no mind is capable of comprehending. There are a half-dozen or more peaks rising from 5,000 to 10,000 feet above the plateau, and these are but stubs of former peaks which have been reduced by erosion.[1] A few of these are worthy of particular mention.

Orizaba, the "shining star" or "Citlaltepetl" of the Aztecs, is a majestic cone which rises from the eastern edge of the plateau to a height of 18,240 feet above the sea, and is visible 80 miles out from the coast.[2] Popocatepetl, the "smoking mountain," is built upon the plateau just south of Mexico City. It rises 17,520 feet above the sea and has a crater half a mile in depth and of the same diameter, from which steam and sulphur gases escape continually, proclaiming it not extinct, but dormant. Ixtaccihuatl, "the woman in white," raises its cone just east of Popocatepetl and to a height of 15,082 feet; and Toluca, called in the Aztec tongue Xinantecatl, and supposed to mean the "nude man," is situated just west of Popocatepetl and rises to a height of 13,000 feet.[3] The Cofre de Perote, or "Nahucampatepetl," to the north of Orizaba, rises to a height of 13,411 feet. Volcano Jorullo in Michoacan belongs to the third era of eruption, which will be discussed under the head of physiographic history, and although not situated on the plateau is a sort of "outlier" of this province. It rises from an amphitheater almost 3,000 feet below the level of the plateau.[4] Colima, on the western edge of the plateau, shows an altitude of 12,664 feet, while numerous other cones, somewhat lower, though scarcely less imposing, dot the plateau in many places. Most of the cones are of the "strato-volcanic" type and show plainly the several flows of which they were built.[5]

The volcanoes of Colima, Popocatapetl, and Orizaba are unique in that they consist of twin peaks, one with a crater and the other without. The names used herewith are applied to the peaks with craters. Their accompanying craterless cones are known respectively as Nevado, Ixtaccihuatl, and Cofre de Perote. From a distance, Nevado appears to have a crater, but this is in reality but a furrow, produced jointly by the sinking of the lava crust and later erosion. The few geologists that have studied the phenomena have apparently avoided giving an explanation of the genesis of the craterless peak, and the single reference available does no more than cite the analogy between these and a type described by Stübel in Ecuador.[1]

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[1] Hill, *Eng. and Min. Jour.*, LXXXV, 681–88.

[2] Melgareo, *Natl. Geog. Mag.*, XXI, 741.

[3] Melgareo, *loc. cit.*

[4] Ordonez, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 9.

[5] Hovey, *Science*, N.S., XXV, 764; T. Flores, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 9, p. 14.

Numerous basins, formed in constructional depressions in the volcanic surface, are scattered over the province. These abound in the environs of the city of Mexico. The city itself is situated in the so-called Valle de Mexico, which is an inclosed basin 50 miles long by 35 miles wide. This basin contains six shallow lakes and a considerable area of marshes. This marsh area is all the more unique and interesting when it is considered that it lies at an altitude a mile and a half above sea-level. The drainage of this basin, which is of the first order of necessity for sanitary living during the rainy season, was an engineering problem which defied successful solution for three centuries. Finally, in 1900, there was consummated a successful plan involving a seven-mile tunnel under the Xalpam Mountain, and an aqueduct over the Guadalupe River, by which the sewage and storm water of the city of Mexico is drained from the basin and emptied into a stream which carries it to the Gulf of Mexico.[2] Many of the basins are filled with water, forming lakes of considerable size, namely, Chapala, Quitzeo, and Patzcuaro, all in the state of Michoacan.

Among other interesting topographic features are the cinder cones and their crater lakes of the Valle de Santiago, and the pit craters of the state of Pueblo. The former are low cones of ash and breccia, eleven in number, the craters of which vary in diameter from 1,500 feet to one mile. The bottoms of some of these craters contain shallow lakes of clear, fresh water (*xalalpascos*). This water is not derived directly from rainfall, but from a subterranean sheet flowing under the porous volcanic soil. The slopes of the craters, both interior and exterior, are frequently covered with green, cultivated fields.[1] These craters are generally regarded as having been produced by explosions caused by steam generated when superficial water came in contact with heated rocks below.[2] The basis of this opinion is the fact that the stratified basaltic flows and beds of tuff forming the plain in which these craters are discovered have not been disturbed profoundly, the eruptions appearing to have been strictly local.[3]

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[1] P. Waitz, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 13, pp. 10–21.

[2] S. F. Emmons, *Science*, N.S., XVII, 309.

The pit craters of Pueblo are apparently similar features. These occupy the centers of cones which rise with very gentle slopes to slight elevations. They are from 3,000 feet to a mile in diameter, and average 150 feet in depth. On the floors of the craters are lakes of fresh water, and their walls show plainly the stratified volcanic beds of which the plain on which they stand is composed. In places are to be observed breccia-filled stream channels, buried under the eruptives which built the cones and formed the craters.[4] Their genesis is no doubt similar to that of the cinder cones described above, though no less an able geologist than Ordonez states that they seem unduly large for the explosive force which is generally regarded as having produced them.[5] Both types of phenomena are relatively recent features of the topography, and probably belong to the second period of vulcanism, to be discussed later.

The important drainage systems of this province are those of the Rio Grande de Santiago, the Rio Lerma, and the Rio Balsas of the Pacific slope, and the Rio Papaloapam with its tributaries and a few small streams of the Atlantic slope. The Rio Lerma is really the upper course of the Rio Grande de Santiago, which is divided about midway in its course by Lake Chapala. The two streams and the lake together form a watercourse about 800 miles in length, the largest in Mexico, if we omit the Rio Grande del Norte, having a drainage basin of about 60,000 square miles. In

[1] Ordonez, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 14.

[2] Hovey, *Bull. Am. Geog. Soc.*, XXXVIII, 730.

[3] Ordonez, *loc. cit.*

[4] W. M. Davis, *Science*, N.S., XXVI, 226.

[5] Ordonez, *Inst. Geol., Mex., Los Xalalpasgos del Estado de Pueblo.*

places its gradient is very steep. Near Guadalajara there is a beautiful falls with a sheer drop of 100 feet, and above La Juntas the stream descends 1,800 feet, over a series of cascades, in a distance of 15 miles.[1]

The structure of this province is difficult to determine, owing to the concealment of all early formations by the more recent extrusives. Where it has been possible to obtain data, however, it has been interpreted as follows: bedrock of massive Cretaceous limestones and shales, folded along east-west axes, badly faulted, cut by granitic intrusives, and covered by a great cap of lava and tuff.

This is the first province to be discussed where the structural trend is east-west. Ordonez thinks that the number and disposition of the volcanic craters along the Rio Grande de Santiago suggests the idea of its marking the line of an important fracture, corresponding to a place of dislocation in the general elevation of the plateau, and where it has brusquely interrupted its direction (northwest-southeast) and effected a movement in a different direction (east-west).

Physiographic history.—The early history of this province is similar to that of the rest of the plateau, as far, at least, as the making of the Cordilleran peneplain and the second uplift; beyond that it is obscure. We may infer, however, that the second erosion cycle had proceeded to the extent of cutting rather deep valleys in the sedimentaries before the first eruptions occurred. The first flows filled these valleys, leaving hills of sedimentaries standing out above them. Erosion continued, and in time these hills were reduced to valleys, and the lava-protected valleys became hills and mountains. Over the greater part of the province later vulcanism completely effaced all traces of these earlier events, and built the great volcanic plain and the peaks which now characterize the province, and it is only around its borders that this part of its history may be determined.[2]

It appears that there have been two periods of vulcanism in this province: the first in the Miocene and affecting all Mexico;

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[1] H. A. Horsfall, *Eng. and Min. Jour.*, LXXXVIII, 665.

[2] Hill, *Eng. and Min. Jour.*, LXXIX, 410.

the second beginning in the Pliocene and continuing to the present time and limited to this province.[1] This second period appears to have been divided into three well-defined epochs: first, that which produced the high peaks and cones; secondly, that which produced the pit craters; thirdly, that which is manifested in the hot springs and geysers of the present time. Between the first and second epochs there was a time of lesser activity during which were produced the minor cones which have since been reduced to slight eminences.[2]

An exception is found in Colima, which according to the classifaction given would belong to the first epoch of the second period. This volcano has erupted at intervals during the life of the present generation. The eruptive material has not consisted of lava, but of glassy fragments of various sizes. It has been assumed that the eruptive forces at work during this latter epoch of activity have not been sufficient to overcome the altitude of more than 12,000 feet, and that therefore the lava rises to a much lower level in the crater and only the hot scoriae are ejected over the sides.[3]

As we have indicated, the second erosion cycle in this province was interrupted by widespread and long-continued vulcanism. Since the cessation of volcanic activity, erosion has again become the dominant factor in making the topography of the province. Shall we call this a continuation of the second cycle or the beginning of the third? Inasmuch as the topographic effects of the second erosion cycle were largely obliterated, and as early youth is manifested over a large part of the province, I believe we are justified in stating that a third cycle is beginning, and although it is by no means certain that the titanic forces which built up this area are exhausted, erosion seems to have the better of vulcanism in the contention for supremacy.[4]

THE SIERRA DEL SUR PROVINCE

Definition and boundaries.—This is the southernmost division of the old Mexican Plateau and is in all essential respects, save the direction of its folds, a counterpart of the northern provinces, from which it has been cut off by the volcanic flows of the province, previously described. It would no doubt fall under the discussion of the Sierra Madre Occidental province were it possible to connect with that. The volcanic area, however, has completely isolated it, and it therefore requires separate treatment. It is an area of odd shape, aligned roughly with the folds, and lies between the volcanic area on the north and the Pacific Ocean on the south.

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[1] T. Flores, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 9.

[2] Ordonez and Aguilera, *op. cit.*, p. 80.

[3] J. M. Arreola, *Jour. Geol.*, XI, 749.

[4] Ordonez and Aguilera, *op. cit.*, p. 80.

The northern boundary has been described, and for the greater part of its length is a natural dividing line separating two regions of widely different types of topography. The Pacific Ocean forms a natural southern and western limit and the remainder of the boundary line is drawn at the foot of the escarpment, where the edge of the plateau rises above the lowlands of the Isthmus of Tehuantepec. (Compare the accompanying sketch map, Fig. 1, with the Bartholomew topographic map previously referred to.)

Topography.—In the general literature of Mexican geology and geography this area is frequently described as though it were a part of the volcanic area. Such description is erroneous, however, for here again the characteristic feature of the topography is plateau dissection. It duplicates the erosional features of the northern provinces and is unaffected by the extrusions which characterize the Volcanic province.[1]

The interior is a labyrinth of mountain ranges trending in diverse directions, with here and there an occasional peak, more resistant than its neighbors or by its configuration less exposed to erosion agencies, rising to a height comparable to that of some of the volcanic cones.

On the Pacific side, head-working streams are rapidly degrading the plateau, leaving its front a tattered edge, with long headlands jutting out between the stream courses. The Rio Balsas, which in its upper course is known as the Rio Mexcala, is one of the most important streams in Southern Mexico, and drains a large portion of the interior of both this and the Volcanic province. The Rio Tehuantepec of the isthmian slope is remarkably straight in its lower course, and without tributaries there. In the upper course, however, it is developing a typical dendritic system of drainage, and is rapidly dissecting the plateau in Oaxaca. The stream was probably originally consequent upon a fault rift in the steep slope of the plateau edge flanking the isthmus, but has since lengthened its course and developed a drainage basin by processes characteristic of subsequent streams.[1]

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[1] William Niven, *Eng. and Min. Jour.*, XC, 672.

The structure on the whole is similar to that described for the northern provinces, namely, folded, faulted sedimentaries, overlain with superficial volcanic material, and intruded by various igneous bodies; but the trend of the folds here is generally east-west. Over the greater part of the province the Miocene volcanic cap has been removed, laying bare the metamorphosed sediments beneath. In addition to having the sedimentaries clearly exposed, we know the character of the actual basement rock—a condition which may only be surmised over the rest of Mexico. The basement rock in this province is Archean crystallines, which may be observed in the deepest canyons not far above sea-level and upward to positions on mountain flanks 6,000 feet above tide.

Physiographic history.—In the other Mexican provinces we were obliged to begin the history at the first post-Cretaceous cycle. Here, although we have Archean rocks determining the topography in places, history must again begin with the Mesozoic era, for the Paleozoic record is a blank. We have Mesozoic sediments resting unconformably on Archean crystallines. How many erosion cycles, or what length of time was necessary completely to remove all traces of Paleozoic rocks and carve deeply into the crystallines, is indeterminable. There is little evidence to warrant the belief that the Mexican Plateau was an island during the Paleozoic era, and consequently without marine sediments. Moreover, there are Paleozoïc rocks exposed in small patches in Sonora, and again in Chiapas and Central America[2] and I believe we may safely infer that they once covered the entire plateau and were removed. After the uplift of the plateau following the deposition of the Mesozoic sediments, the history of this province becomes coincident with that of the northern provinces.

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[1] Bose, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 31, p. 21.

[2] Hill, *Eng. and Min. Jour.*, LXXXIV, 63.

THE TEHUANTEPECAN PROVINCE

Definition and boundaries.—This province comprises an area of very old, low-lying rocks occupying the Isthmus of Tehuantepec. If we were to draw province boundaries on a basis of topography alone we should be obliged to include most of this area in the Gulf Coastal Plain province, for there is scarcely any difference in topography. But considering also structure and history, we are compelled to make this a separate province, with boundaries as indicated on the accompanying sketch.

It is bounded north and south respectively by the Gulf of Mexico and the Pacific Ocean. The greater part of the western boundary is the scarp of the plateau, which rises 8,000 feet above the isthmus,[1] while to the east the heights of Chiapas rise to an almost equal altitude.[2] Between these two highland areas lies the isthmus, like a great block dropped out of an arch.

Topography.—The isthmus is an area of low, rounded hills, with two regional slopes, the longer toward the north and the shorter toward the south, the two slopes meeting to form a divide at Tarifa Chivela. Both slopes are very gentle, and the maximum altitude at the divide is less than 800 feet.[3]

The drainage follows the regional slopes, regardless of structure, the Rio Coatzalcoalcos and its tributaries draining northward, and the Rio Geronimo, southward.

Physiographic history.—The oldest rocks exposed in this province are the Archean crystallines, in the vicinity of Tehuantepec. Farther up the slope at Chivela are metamorphosed sediments of probable Paleozoic age, and still higher, unaltered Middle Cretaceous and Upper Miocene. Down the Atlantic slope, Pliocene deposits grade into the Recent sediments of the coastal plain.

It may be a permissible figure to speak of the isthmus as a block dropped out of an arch, but as a matter of fact it will require us to postulate more profound changes than the mere dropping of a fault block to account for the peculiar structure of the isthmus.

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[1] Hill, *Trans. A.I.M.E.*, XXXII, 163.

[2] Bose, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 31.

[3] Bose, *op. cit.*, profile sketch.

The low mountain chain running through Tarifa Chivela is probably a spur of the Mexican Mountains—a southward extension of the Sierra Madre Occidental perhaps—that came into existence with the Cretaceous-Eocene uplift; the plicated and metamorphosed sediments are to us as a mutilated page torn from an important but now missing chapter in our historical account of Mexican physiography; and the low swells and undulations of the Atlantic slope are the result of the uplift and deformation that "constructed the bridge between the two American continents."[1]

Summing these events up in chronological order we may say that upon the fundamental Archean complex were deposited a series of Paleozoic rocks of unknown thickness and areal extent. These were so profoundly deformed as to become highly metamorphosed. Following the deformation came a period of erosion which probably continued until the Middle Cretaceous submergence. In other words, the pre-Mesozoic history of this province probably was coincident with that of the Mexican Plateau, of which the isthmus was no doubt an integral part. At the time of the uplift referred to a great structural movement took place which cut this province off from the remainder of the plateau, the place of rupture being still visible in the great scarp in Oaxaca. The dropping of the block on the east of this fault line brought about the inundation of what is known as the isthmus. The character and distribution of the Tertiary deposits would indicate that the submergence thus produced was not to great depths. In late Tertiary and early Quaternary time an orogenic movement took place which produced a second series of folds, and raised the isthmus above the sea. This movement is to be regarded as an event peculiar to Central America, at all events to that part of the country south of Oaxaca. The Mexican Plateau was not affected.

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[1] Bose, *op. cit.*, p. 26.